16.—An Unusual Adularia from the Billeranga Hills, Western Australia

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K-feldspar phenocrysts in trachyte from the Billeranga Hills (Western Australia) have Carlsbad and Manebach twins, and exhibit a range in optical properties apparently caused by partial inversion to microcline. Unusually slow cooling of the magma, perhaps aided by other effects, may be responsible.

Introduction

The Billeranga Hills are near the western edge of the Precambrian shield of Western Australia, about 225 miles by road north of Perth, and about 30 miles by road east of Mingenew. The sequence consists of unmetamorphosed, interbedded flows and sandstones of probable Proterozoic age, but has not, so far, been investigated in detail.

Petrography

The K-feldspar described below occurs in an iron-stained trachyte specimen† from a flow near the bottom of the sequence. The rock is red-brown and amygdaloidal with phenocrysts of light grey K-feldspar, generally about 0.6 mm long, in a red-brown groundmass. The groundmass contains numerous dendritic aggregates of black iron ore and is so impregnated with limonite as to be locally opaque. Translucent patches are optically anisotropic, with low birefringence and irregular, wavy extinction, suggestive of incompletely crystallized feldspar. Feldspar phenocrysts range in shape from almost euhedral to anhedral, and some of the latter may have been partly resorbed. The grains contain numerous inclusions of red-brown and black iron ore, some aligned parallel or nearly parallel to (010) and (001) but most without apparent preferred orientation. The amygdales are irregularly shaped and are mostly about 0.5 mm in diameter, although some are considerably larger. They generally consist of quartz with undulose extinction, and are all heavily charged with iron ore inclusions. Some amygdales also contain pale yellow fibrous aggregates of a mineral the relief and birefringence of which are slightly greater than quartz. The fibres have straight or nearly straight extinction, are length-slow, without discernible pleochroism, and are commonly radiating. This mineral, which also partly replaces a few feldspar grains, is probably deuteric, and may be a variety of chlorite.

Approximate composition of the rock, from visual estimation, is:

	%
Groundmass	46
K-feldspar	40
Quartz	8
(?) Chlorite	6

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Chemical Composition of the Feldspar

Concentration of iron ore inclusions is generally lower in the feldspar than in the quartz amygdales and groundmass, enabling a preliminary gravity separation of feldspar from the crushed rock in bromoform. Magnetic separation in the Franz isodynamic separator eliminated remaining fragments of groundmass, feldspar with a high concentration of iron ore inclusions, and most of the quartz. The residue consisted of feldspar and a little quartz, both with a few iron ore inclusions. A count of 1,000 grains under the microscope indicated a composition for the residue of 97% feldspar, 3% quartz. Partial analysis of the residue with the Lange flame-photometer showed K_2O 16.18%, Na_2O 0.36%, CaO 0.01%‡. The feldspar is, therefore, highly potassic and contains about 16.7% K_2O, 0.4% Na_2O and 0.01% CaO.

Measurement Technique

Measurements of the feldspar were made with a four-axis Universal Stage, and were plotted on a Schmidt (equal-area) net. Where possible, only grains with both optic axes accessible were selected. A procedure based on the direct method outlined by Fairbairn and Podolski (1951), and designed to eliminate instrument errors, was adopted. Each recorded value of 2V represents the average of eight direct measurements, and is considered reproducible to within 1°, and generally to within ½°. The average of eight measurements was recorded for each accessible principal optical direction, and the inner stage was rotated through approximately 180° after each measurement. The same technique was adopted when measuring and recording positions of poles of composition and cleavage planes. All measurements were made with white light, as high intensity was necessary.

The two accessible optical directions in grains selected for measurement are Y and Z. Where both optic axes are measured directly, X, midway between them, can be plotted on the projection, and need not be located by construction from Y and Z. This provides a useful check on the overall precision of measurement and plotting, for X and Z should lie 90° apart.

Morphology and Optics of the Feldspar

Notable features of the morphology and optics of the feldspar are listed below, and their probable significance is discussed later.

(i).—Some fairly euhedral grains are present, but others have irregular outlines suggestive of resorption.

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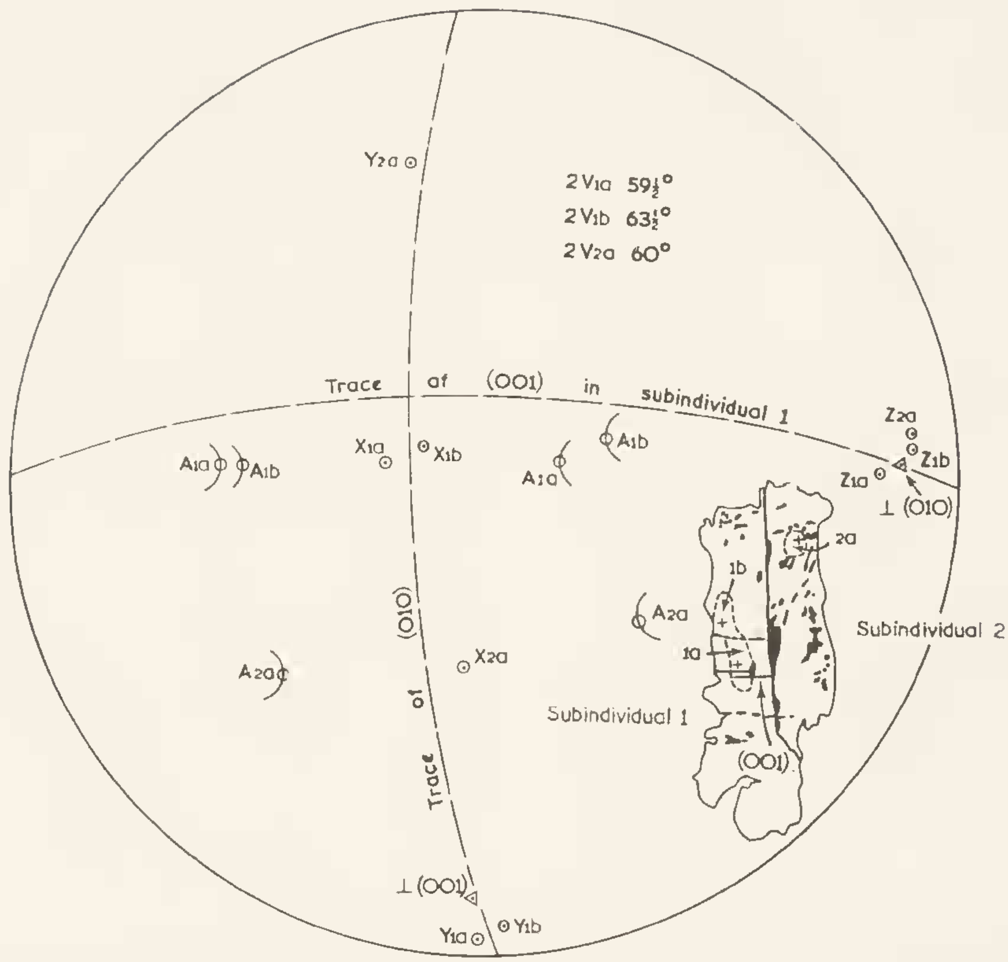

Fig. 1.—Equal area projection (lower hemisphere) of optical and crystallographic data from an adularia grain with Carlsbad twins. Points in the grain at which measurements of 2V and the directions of Y and Z were made shown thus +. The points are enclosed by dashed lines indicating the extent of the area in which extinction is fairly constant.

(ii).—Most grains are twinned on the Carlsbad law, but some are twinned on the Manebach law.

(iii).—No subindividual has completely uniform extinction. Carlsbad and Manebach twin laws can be established from measurements of the mean extinction positions for each subindividual.

(iv).—Patchy, irregular extinction is caused by different orientation of the optical indicatrix in different areas of the same subindividual. The maximum observed variation of a principal optical direction in two adjacent areas of one subindividual is 13° (see X_{2a} and X_{2b} in Fig. 2).

(v).—In some places there are minute, poorly defined, intersecting lamellae, parallel in a general way to (010) and (001). They suggest incipient albite and pericline twins, and are generally confined to small, irregularly shaped, isolated patches in the grains.

(vi).—2Vα may range considerably in different areas of the same grain, the maximum observed difference being 12½°. The overall range of 2Vα in ten measured grains is 15° (52½° to 67½°).

(vii).—Cleavages and twin composition planes are bent and distorted in some grains by up to 5°.

(viii).—Areas of uniform extinction in the grains are commonly too small to measure 2V precisely, or to establish the orientation of the indicatrix. Measurements were confined to patches in which extinction appeared uniform over a sufficiently large area for consistently reproducible results.

Twin Laws

Apart from apparent patches of incipient albite and pericline twins, grains contain only two subindividuals. These latter twins fall into two categories, parallel and normal.

Parallel twins

Although any one principal optical direction varies in different areas of a subindividual, a mean position for it on the projection can be assumed. Approximate location of the twinning axis from intersection of great circles joining mean positions of X_1X_2, Y_1Y_2 and Z_1Z_2 is possible. In parallel twins the triangle of error, even where large, is generally close enough to the trace of the twin composition plane to prevent ambiguity and to demonstrate parallelism. In such twins, the mean positions of X_1 and X_2 are about 40° apart, and displacement of cross cleavages in the two subindividuals is about 50°. The cross cleavage (001) and composition plane (010) are identified by proximity of their poles to principal optical directions. The above features identify the Carlsbad law (see Fig. 1).

Normal twins

The twin axis, with its approximate position located as described above, is generally sufficiently close to the normal to the twin composition plane to prevent ambiguity. In these twins, the mean positions of X_1 and X_2 are about 14° apart, and the twin composition plane is (001). (010)

cleavages are parallel in both subindividuals, as are (001) cleavages. Cleavages are readily identified by proximity of their poles to principal optical directions, and by their relative development—(001) perfect, (010) distinct. The above features identify the Manebach law (see Fig. 2).

In practice, the perfect (001) cleavage parallel to the twin composition plane in Manebach twins generally allows their immediate distinction from Carlsbad twins, which have the less well-developed (010) cleavage parallel to their twin composition plane.

Nomenclature

The optic plane of the K-feldspar described above is normal or nearly normal to (010) and $2V\alpha$ ranges from $52\frac{1}{2}^\circ$ to $67\frac{1}{2}^\circ$. According to the modification of Spencer's optical classification set forth by Chaisson (1950, p. 538), the feldspar is best called adularia. However, the Z direction, which in optically monoclinic adularia should coincide with the normal to (010) (the *b* crystallographic axis), is not constant everywhere in the same grain. Distortion of some grains, evident from bent cleavages, cannot fully account for all variations in orientation of the indicatrix, for many adjacent areas with notably different optical orientation are traversed by clearly defined, continuous and undistorted cleavage. In such areas, observed differences in optics are probably due to varying degrees of departure from the ideal monoclinic symmetry, that is, to varying degrees of triclinicity. The optics and chemical composition of the mineral thus indicate that it lies in the region of intermediate microclines outlined by MacKenzie and Smith (1956, Fig. 1, p. 406).

Discussion

Existence of high- and low-temperature forms of alkali feldspar is now well recognised. Following Barth's conception of polymorphism in K-feldspar (Barth, 1934), Laves (1950), postulated an order-disorder relationship in the location of the Al and Si atoms between high- and low-temperature forms of K-feldspar. In sanidine, the monoclinic modification stable at high temperature, Al and Si are disordered: in microcline, the triclinic modification stable at low temperature, Al and Si are ordered. The concept is expanded in later papers Goldsmith and Laves, (1954*a*, 1954*b*).

Departures from the monoclinic optics hitherto generally assumed for adularia have long been recorded, and have been described recently from optical work by Köhler (1948) and Chaisson (1950), and from X-ray work by Laves (1950) and Goldsmith and Laves (1954*a*, 1954*b*). The last-mentioned assume a continuous range in triclinicity from 0 in monoclinic K-feldspar to 1 in "maximum" microcline. This range is a function of Al-Si order-disorder, and feldspars with intermediate triclinicity are stated to be

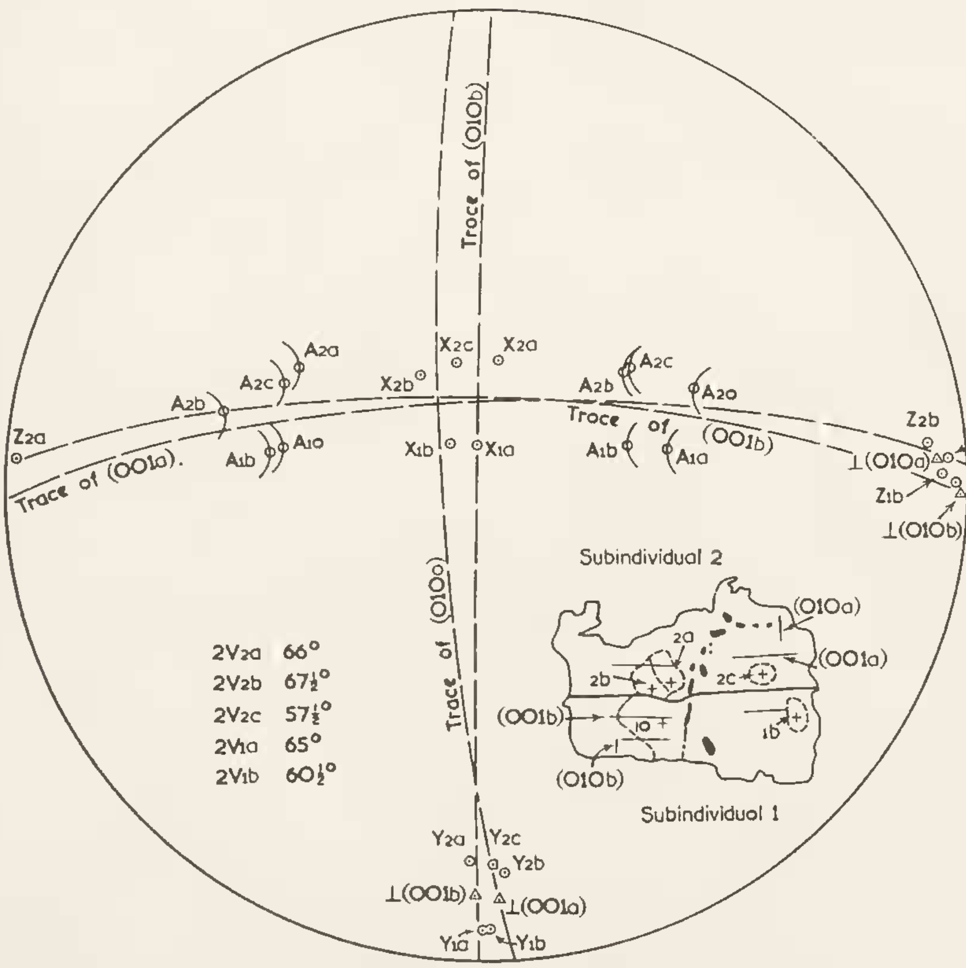

Fig. 2.—Equal area projection (lower hemisphere) of optical and crystallographic data from an adularia grain with Manebach twins. Points in the grain at which measurements of 2V and the directions of Y and Z were made shown thus ·+. The points are enclosed by dashed lines indicating the extent of the area in which extinction is fairly constant.

not uncommon. They have observed large variations in triclinicity in the same "crystal," and assume from earlier work (Laves 1950) that the characteristic combination of albite-pericline twinning in microcline indicates inversion from an original monoclinic crystal. Orthoclase, although apparently optically monoclinic, is considered by Goldsmith and Laves to consist of submicroscopic units, with all possible degrees of Al-Si order, and it cannot be assigned a well-defined stability field.

Transformation of the stable or metastable high-temperature forms of K-feldspar to the highly ordered triclinic form is very sluggish and, unlike the reverse process, has not so far been observed in the laboratory. General restriction of microcline to granitic rocks (whether conceived to be essentially magmatic or essentially metamorphic in origin) is probably due to the long time available for transformation under equilibrium conditions, during slow cooling at great depths. Virtual absence of microcline from volcanic rocks is probably due to rapid, commonly spasmodic cooling at relatively shallow depths, quenching the stable high temperature monoclinic modification (sanidine) and the metastable optically monoclinic modifications (orthoclases). However, with unusually slow cooling, perhaps accompanied by favourable, as yet unknown physico-chemical conditions, partial inversion to the more ordered form in some volcanic rocks is likely. Grains showing such inversion are probably best sought in rocks such as trachytes, which are normally differentiates, and are thus likely to be products of slow cooling in the magmatic chamber.

Conclusions

The optics of adularia from trachyte in the Billeranga Hills are thought to have arisen from processes set out above. If so, the distortion in some grains, revealed by bent cleavage and composition planes, is likely to have resulted from internal strains caused by numerous centres of inversion. The hypothesis is strengthened by the presence of small patches of poorly developed cross-hatching in many grains. Origin of the irregular boundaries of some grains is not certain: they may have been caused by resorption during release in pressure on extrusion of the lava.

In view of the probable factors causing their inversion detailed optical work on naturally occurring K-feldspars may eventually help in unravelling the cooling history of extrusive rocks in which they are found, even though the value of K-feldspars as absolute indicators of geologic temperature is now suspect.

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